Current Dissemination of Imagery

What and how compression is used in today's USIGS system.

United States Imagery and Geospatial Information Service

Imaging Satellite

Tactical

NITFS JPEG

DCGS

NITFS JPEG

NATO and Coalition

NITFS JPEG

NITFS JPEG

1.3 DCT

Receive Locations

NIMA Library

NIMA Method 4

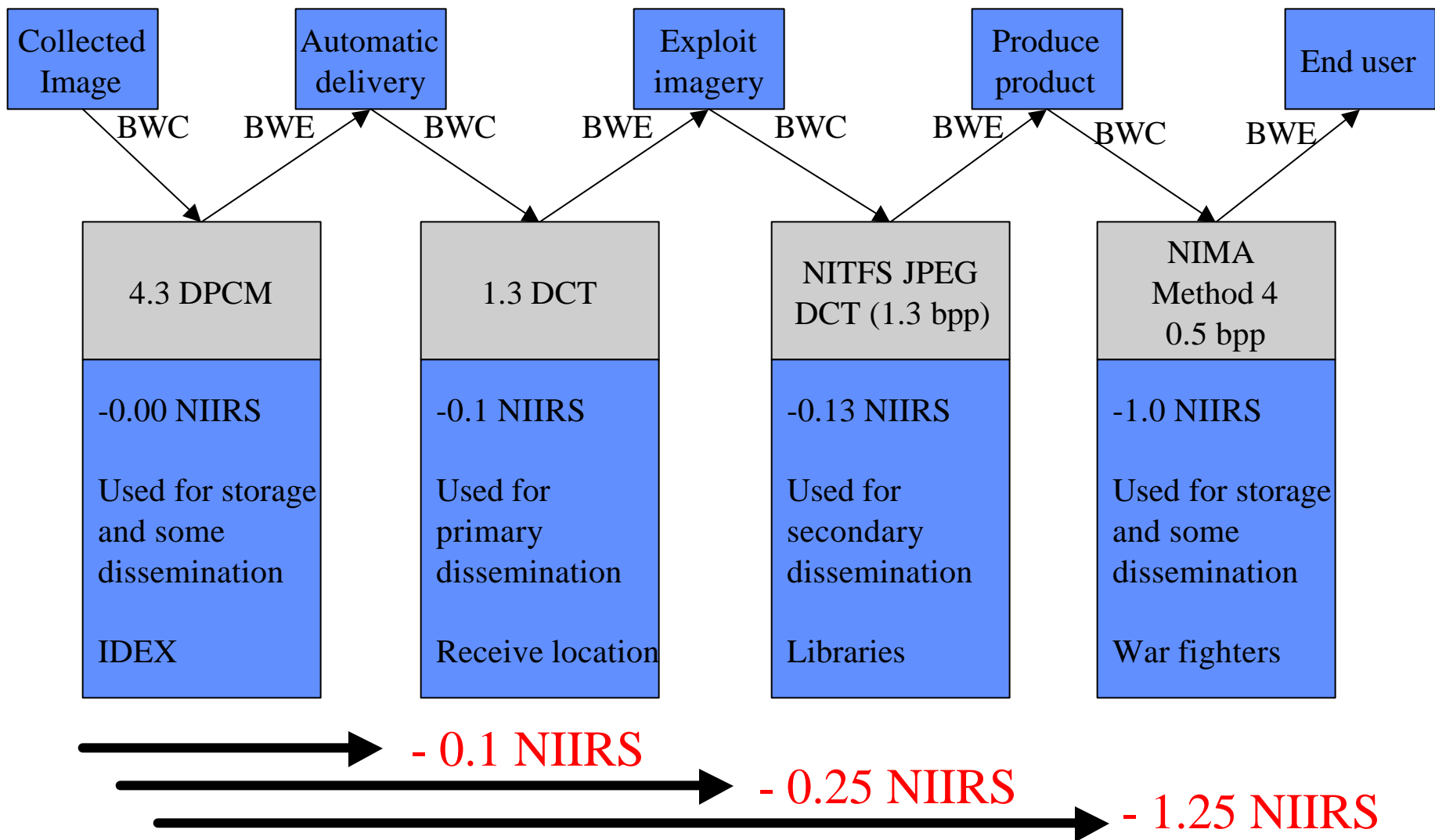Processing Station
4.3 DPCM

D2C

2.3 DCT

NITFS VQ

War Fighter
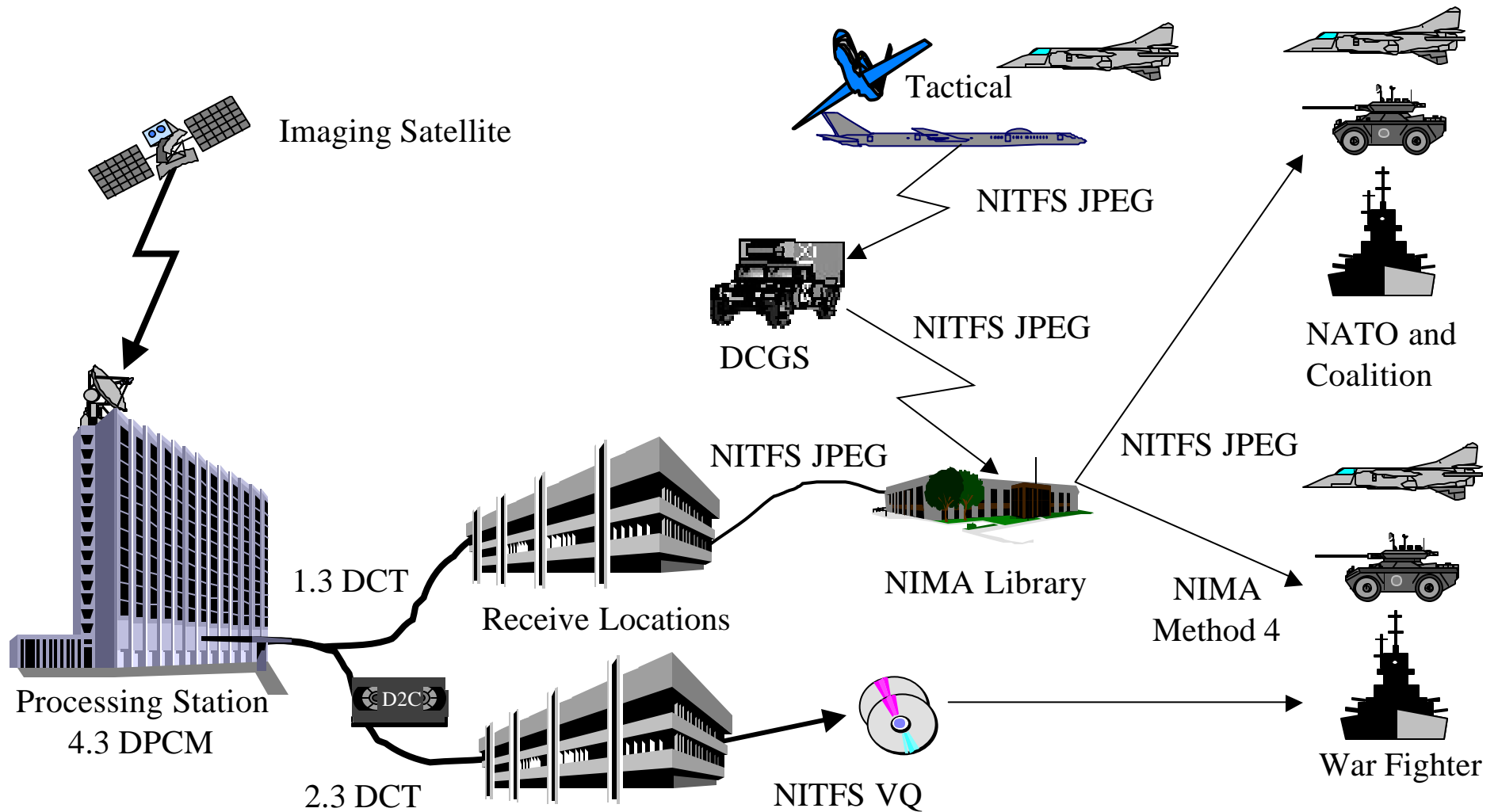
Current USIGS Compression of Imagery

- The primary system's compression algorithms were developed for high quality for primary dissemination and exploitation of data.

- The secondary system's compression algorithm was adopted from commercial sources because of flexibility and COTS availability.

- The tactical BWC was derived from JPEG to be backwards compatible and meet the tactical dissemination requirements.

4.3 DPCM	1.3 DCT	NITFS JPEG DCT (1.3 bpp)	NIMA Method 4 0.5 bpp
-0.00 NIIRS Used for storage and some dissemination IDEX	-0.1 NIIRS Used for primary dissemination Receive location	-0.13 NIIRS Used for secondary dissemination Libraries	-1.0 NIIRS Used for storage and some dissemination War fighters
Primary Users		Secondary Users	Tactical Users

USIGS Dissemination of Imagery

Collected Image	Automatic delivery	Exploit imagery	Produce product	End user

BWC BWE   BWC   BWE   BWC   BWE   BWC   BWE

4.3 DPCM	1.3 DCT	NITFS JPEG DCT (1.3 bpp)	NIMA Method 4 0.5 bpp
-0.00 NIIRS	-0.1 NIIRS	-0.13 NIIRS	-1.0 NIIRS
Used for storage and some dissemination	Used for primary dissemination	Used for secondary dissemination	Used for storage and some dissemination
IDEX	Receive location	Libraries	War fighters

- 0.1 NIIRS

- 0.25 NIIRS

- 1.25 NIIRS

Current Compression Algorithms

- The primary system's compression algorithms (1.3 DCT, 2.3 DCT and 4.3 DPCM) were developed for high quality (0.2, 0.1 and 0.0 NIIRS loss or less respectively) for primary dissemination and exploitation of data.
  - The number of images passed through the primary dissemination path and the quality of those images meet the requirements.
  - Algorithms not commercially available (no COTS, Datamaster)
  - Does not meet the requirements and flexibility of the secondary requirements
- The secondary system's compression algorithm (JPEG) was adopted from commercial sources because of flexibility and COTS availability.
  - The quality at the desired bit rate does not meet requirements of primary systems.

Compression Overview

Compression Algorithm	Transform Technique	Quantization	Encoding	Comments
4.3 DPCM	Linear prediction from neighboring pixels	Table look-up	Variable length Huffman encoding	• Low complexity • High quality • Low compression ratio
NITFS JPEG DCT	8-by-8 block Discrete Cosine Transform (DCT)	Human Visual System (HVS) Response quantization in DCT space	Variable length Huffman encoding	• Can be rate controlled • 8-by-8 transform used for speed
1.3 / 2.3 DCT	32-by-32 block DCT	HVS quantization	Variable length Huffman encoding	• Rate controlled to either 1.3 bpp or 2.3 bpp
Vector Quantization	No transform performed	Vector code book matching	Code book numbers	• Low channel error susceptibility
NIMA Method 4	Down-sampled followed by JPEG DCT	JPEG DCT	JPEG DCT	• Achieves very low bit rate at reasonable quality
JPEG 2000	Wavelet-based sub-band transform	Scalar Quantization with Dead-Zone	Bit-Plane Arithmetic encoder	• Highest quality of any of the algorithms • Most functional

Bernie Brower

Compression Overview

Algorithm	Advantage	Disadvantage
4.3 DPCM	• Low complexity (low power/size/weight) • Visually lossless quality • Low memory requirements • Government standard • Rate controlled	• Low compression ratios compared to frequency-based transform techniques.
1.3 DCT	• High quality • Military standard • Rate controlled	• High complexity (32-by-32 transform, rate-control) • Blocking artifacts
2.3 DCT	• Near lossless quality • Government standard • Rate controlled	• High complexity (32-by-32 transform, rate-control) • High bit rate (2.3 bpp)
NITFS JPEG DCT	• International/commercial standard • Low cost implementation (COTS) • Low complexity (8-by-8 transform)	• Blocking artifacts • Lower quality than 1.3 DCT and wavelets
NITFS VQ	• Low complexity for decompression • Low susceptibility to channel error • High quality on DMA maps • Military standard	• High complexity for compression • Relatively poor quality on images
NIMA Method 4	• Interoperable with NITFS JPEG • High quality at low bit rates • Military standard	• Does not perform well at higher bit rates • Not flexible
Wavelets	• Better quality to compression ratio than any other compression algorithm • Significantly more functionality • Commercial Standard	• Large memory requirements • Computational Complexity • Significant start-up cost

Compression Rate Improvement Over Time

(Constant Quality)

Approximate Image Quality loss
IDEX Storage -0.00 NIIRS
DMA   -0.10 NIIRS
Primary   -0.20 NIIRS
Secondary   -0.50 NIIRS

Assumes Wavelet is a standard and is used in 2000 time frame
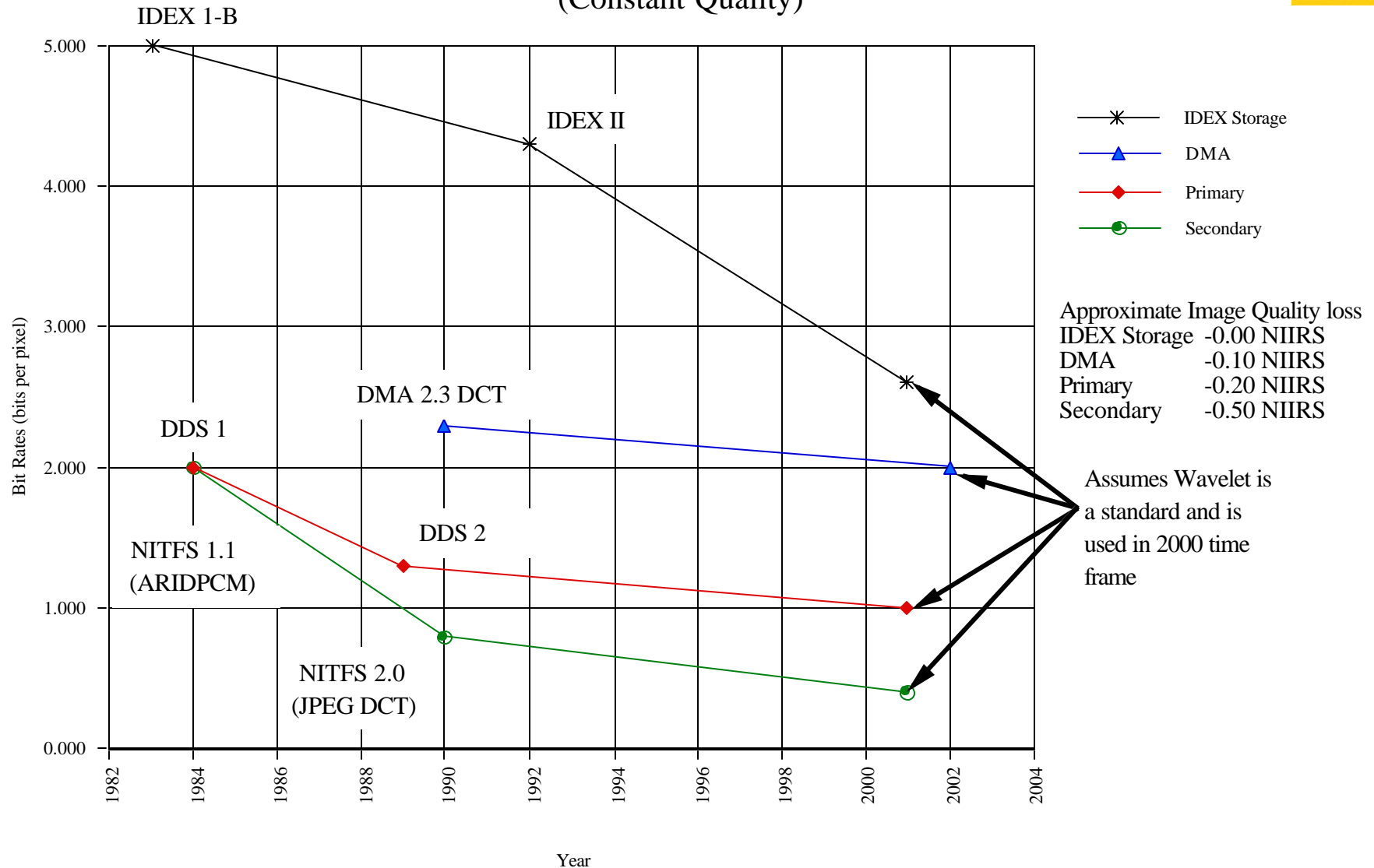
Related Issues (File Formats)

- **TFRD**
  - Used for primary dissemination
  - End users exploit imagery to develop image products
    - Requirements included SDE information
  - Does not include graphics or overlays

- **NITFS**
  - Used for secondary dissemination of exploited data
  - End users only use imagery and do not exploit imagery
  - Require graphics and overlays

- The two are trying to extend their file format and compression to incorporate the others needs.
  - NIMA now has control over all of the systems (primary/secondary)

Migration of USIGS to JPEG 2000

Old Compression Paradigm (JPEG Baseline)
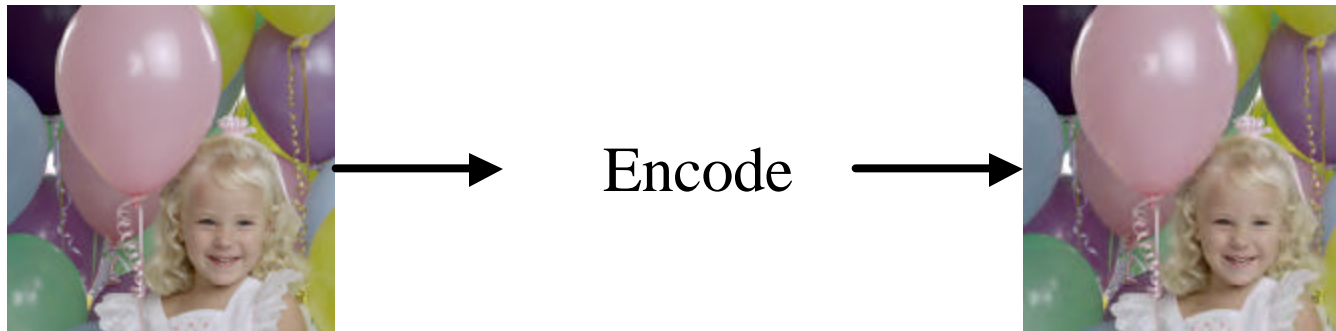
Encode

Encoder choices

color space

quantization

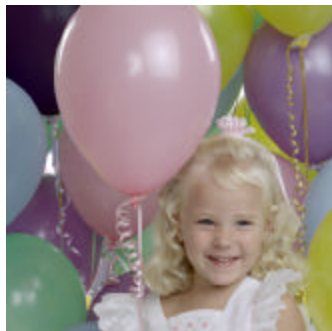entropy coder

pre-processing

No decoder choices

only one image

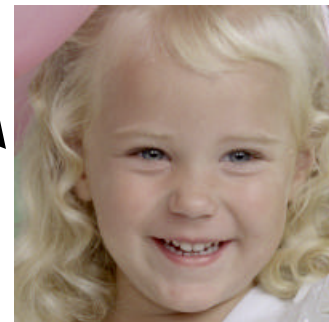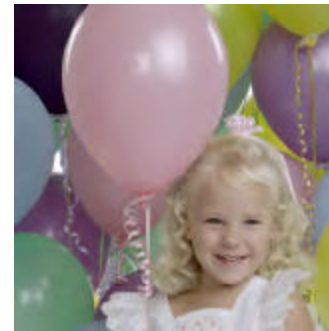post-processing

New Compression Paradigm

Encode choices

Old paradigm choices +
Contone or binary
Tiling
Lossy/lossless
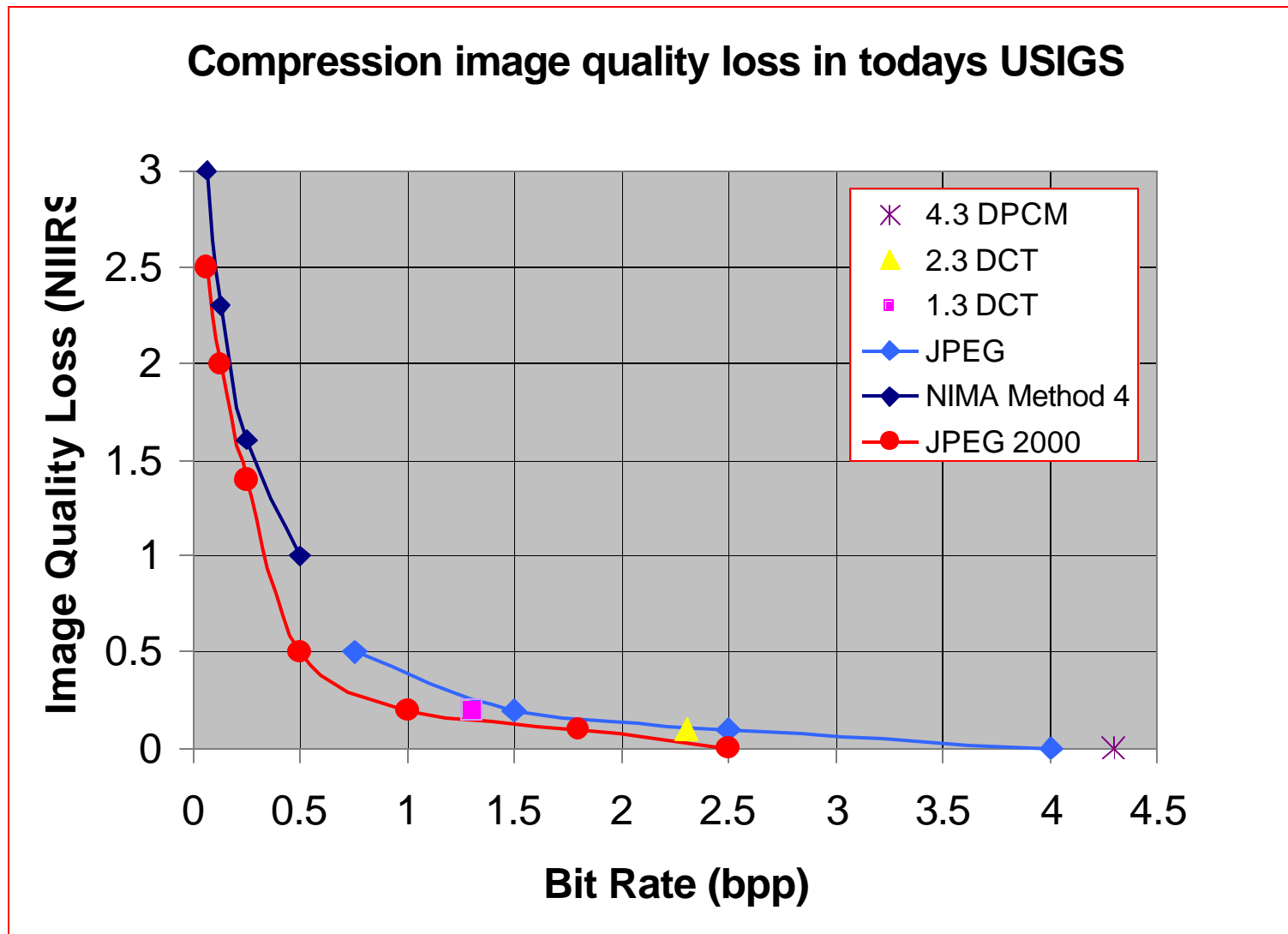
Encode

Decode choices

Image resolution
SNR fidelity
Visual fidelity
Target filesize
Lossless/lossy
Region-of-interest

Power of JPEG 2000

- ## Image Quality
  - JPEG 2000 will meet or exceed the current image quality requirements for all segments and applications within the USIGS architecture.
    - Does not currently meet some quality requirements for SAR.

- ## Increased functionality
  - JPEG 2000 uses an embedded, progressively encoded bit stream for the compressed file. This enables the following kinds of scalability:
    - Progressive by accuracy (SNR), visual quality, and resolution (RRDS).
  - Markers are placed in compressed bit stream to give the decompressor many choices in decoding the file:
    - Any desired bit rate, resolution layer, or a tile (sub-image)
      - Today's algorithms are limited to given bit rates, single resolution, full image.
  - Region of Interest (ROI) encoding.

Bernie Brower

Power of JPEG 2000

- JPEG 2000 will be an international commercial standard, which makes it a logical solution from a cost and interoperability point of view as systems migrate to COTS products.

- JPEG 2000 will have the capability to handle multi-component imagery, allowing it to process MS/HS data.

- The single, unified compression standard will handle:
  - Any bit depth from 1 bpp (e.g. binary FAX) to 16 bpp.
  - Any arbitrary bit rate or quality that is desired, up to and including lossless.
    - Today's algorithms only operate at specific discrete rates (or quality levels for JPEG) and bit depths and thus are not as flexible.
  - Any image size no matter how big (i.e. with a tiling mechanism).

Image quality improvement across the board

Compression image quality loss in todays USIGS

Image Quality Loss (NIIRS) vs Bit Rate (bpp)

Legend:
- 4.3 DPCM
- 2.3 DCT
- 1.3 DCT
- JPEG
- NIMA Method 4
- JPEG 2000

Embedded Bit Stream Example w/ USIGS-Equivalent Rates

| 2.6 bpp |
| (4.3 DPCM-equivalent visually lossless archive quality) |

1.0 bpp
(1.3 DCT-equivalent quality)

0.8 bpp

0.8 bpp

Compressed
Bit Stream

1.8 bpp
(estimate of 2.3 DCT-equivalent quality)

start of
compressed file
(most important bits)

end of
compressed file
(least important bits)
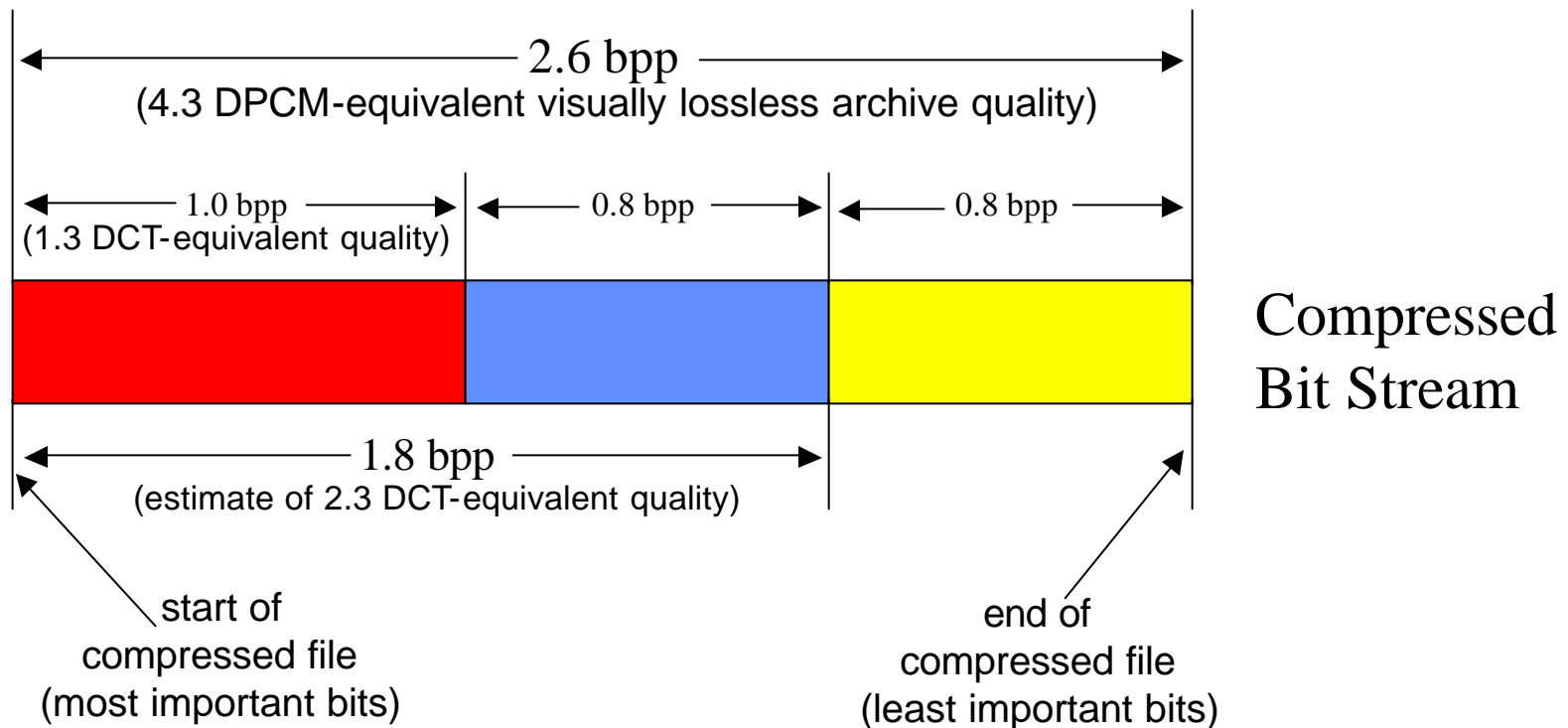
Compress to a very high quality (rate). Then, any quality (rate) less than that can be obtained by truncating compressed bit stream.

Example of Progression by Accuracy

Original image was 8-bit uncompressed. All images extracted from a <u>single</u> 2.0 bpp compressed file.

With an embedded, progressively encoded bit stream, simply compress to high quality once and then decode the portion of the bit stream that meets your bandwidth requirements.

Example of Progression by Accuracy

Original image was 8-bit uncompressed. All images extracted from a <u>single</u> 2.0 bpp compressed file.

With an embedded, progressively encoded bit stream, simply compress to high quality once and then decode the portion of the bit stream that meets your bandwidth requirements.

Examples of Progression by Resolution

Examples of Progression by Resolution

1/4 Resolution

1/2 Resolution

Original image was 8-bit uncompressed.

All images extracted from a single 1.0 bpp compressed file. Low resolution thumbnails are stored at the front of the file and more and more resolution is added as the decompressor reads in more of the file.

Full Resolution

RRDS generation is a natural part of compression or decompression in a wavelet-based algorithm.

ROI Example

ROI Selected ROI has bit rate of 2.0 bpp

Image compressed to a bit rate of 0.0625 bpp

Net rate for entire image is 0.12 bpp

Bernie Brower

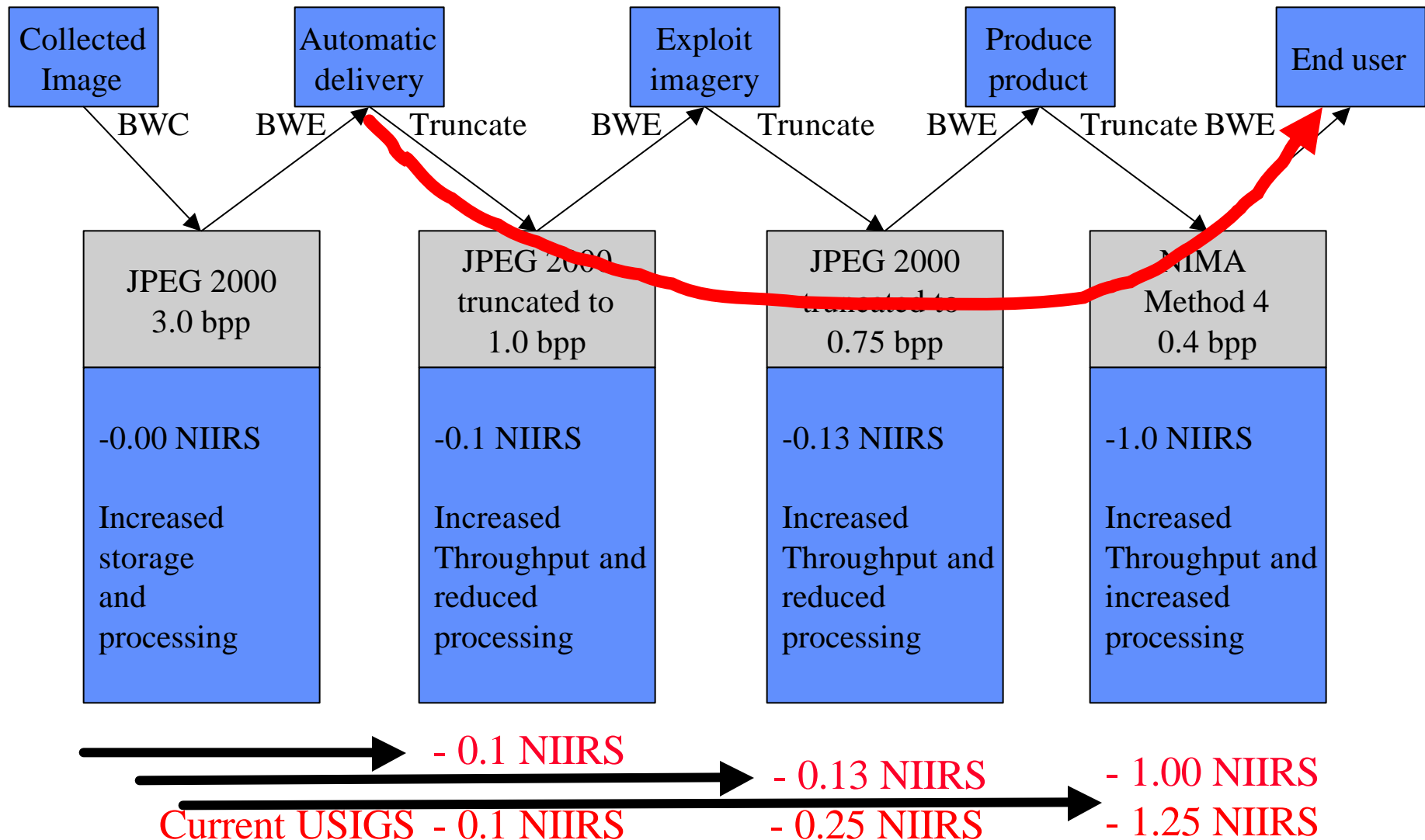# Multispectral / Hyperspectral Imagery

- More and more multi-band systems in the future.
  - Tactical MSI (e.g. SYERS)
  - Commercial MSI (e.g. Space Imaging, Earthwatch):
  - Tactical HSI (e.g. NEMO, Warfighter)
- MS data will be archived in public and private image libraries once systems are operational.
- Current compression and dissemination techniques do not efficiently represent MS and HIS data.

Commercial Interoperability

- Microsoft and Apple have already demonstrated prototype JPEG 2000 browser applications

  – Most new computers will have this built into the operating system.

- Companies that are active in imaging over the internet view this as a significant improvement to the compression that is currently used on the internet.

  – Adobe, Netimage, Netscape, AOL, IBM, Kodak, . . .

- The digital camera companies are all active in the JPEG 2000 committee and should produce digital camera's by 2001.

  – Fuji, Sony, Kodak, Cannon, Sharp, Mitsubishi, HP, Ricoh, Samsung.

USIGS Dissemination of Imagery

Collected Image	Automatic delivery	Exploit imagery	Produce product	End user

BWC   BWE   Truncate   BWE   Truncate   BWE   Truncate BWE

JPEG 2000 3.0 bpp	JPEG 2000 truncated to 1.0 bpp	JPEG 2000 truncated to 0.75 bpp	NIMA Method 4 0.4 bpp
-0.00 NIIRS	-0.1 NIIRS	-0.13 NIIRS	-1.0 NIIRS
Increased storage and processing	Increased Throughput and reduced processing	Increased Throughput and reduced processing	Increased Throughput and increased processing

- 0.1 NIIRS

- 0.13 NIIRS   - 1.00 NIIRS

Current USIGS - 0.1 NIIRS   - 0.25 NIIRS   - 1.25 NIIRS

Bernie Brower

JPEG2000 Compression Standards

- The standard only specifies a decoder and a bitstream syntax and is issued in several parts:
  - **Part I:** specifies the minimum compliant decoder (e.g., a decoder that is expected to satisfy 80% of applications); International Standard (IS) has been approved 12/30/00. This has currently been published by the ISO.
  - **Part II:** Describes optional features and value added extensions. International Standard (IS) was approved 1/10/01.
  - **Part III:** Motion JPEG 2000 with file format from MPEG 4. International Standard was approved.
  - **Part V:** Reference software: Two versions of reference software (JAVA, C++). International Standard was approved. The US has brought concerns that the reference software is currently not fully compliant to the Part 1 standard.

Future Standards

- Currently being worked standards that will be passed within the next year:
  - **Part IV:** Compliance testing procedures. The FDIS will be up for ballot in February 2002. Compliance test image and procedures are very important for the promotion of "compliant" standards and interoperability.
  - **Part VI:** Compound document. Being developed to support compound documents (text, graphics, and images) using the Mixed Raster Content (MRC) defined in ISO 16458. Currently at FCD.

New Work Items

- **Part 8: Security: JPSEC**
  - Security issues, such as authentication, data integrity, protection of copyright and intellectual property, privacy, conditional access, to mention a few, are among important features in many imaging applications targeted by JPEG 2000. This part of JPEG 2000 standard intends to provide tools and solutions in terms of specifications in order to allow applications to generate, consume, and exchange SECURE JPEG 2000 bitstreams.

New Work Items

- ## **Part 9: Interactivity tools, APIs and Protocols**
  - This part would support user interaction with JPEG 2000 images by providing APIs whereby applications could exploit JPEG features and protocols whereby this interaction can occur remotely over networks.
  - Interactivity is a key component in many multimedia applications. Interactivity, in local or remote, often requires rules and syntax to for exchange of information. As an example, a thin client may wish to browse through a very large image present on a server without requiring transmission of the whole image, Part 11 of JPEG 2000 intends to provide further specifications to previous JPEG 2000 parts in order to allow for flexible yet interoperable interactions.

New Work Item

- **Part 10: 3-D and floating point data**
    - This part will provide a mechanism for compression and decompression of volume data.
    - JPEG 2000 Part 1 provides encoding and decoding mechanisms for two-dimensional image data. Part 2 provides extension to multiple components via decorrelating transforms. However, there is no provision for encoding across the decorrelated components. There is only two-dimensional encoding among the decorrelated components. Therefore, this part will provide the means for encoding directly three-dimensional set of original or transformed data. The applications are to volume imagery, usually gathered by tomography to create a volume medical, biological or geological images, or to measurement data associated with a three-dimensional grid.

JPEG 2000 USIGS Status

- ISO has passed JPEG 2000 Part 1 and 2
  - www.JPEG.org
- JPEG 2000 is a mandated standard for NIMA and the NRO
- NIMA has selected JPEG 2000 as Part of NITFS 2.1
- NRO has selected JPEG 2000 as the compression algorithm of future capabilities
- NATO has selected JPEG 2000 as part of STANAG 4545
- NIMA is currently defining a profile of JPEG 2000 with recommended practices and an implementation guide
  - Available on NIMA web site (http://164.214.2.51/ntb/hot/)
    - NIMA-Imagery-NTB-What's hot
- Recommendations hold for NRO, NIMA, NATO, and Tactical

Bernie Brower

JPEG 2000 Interoperability

- The NIMA profile document will define parameters that will assure image quality, functionality, and interoperability

    – Recommended parameters were selected with the architecture, users, and future applications in mind

    – NRO future capabilities are compliant to this profile

    – CIGSS has funded migration tasks to JPEG 2000

    – NATO is currently reviewing and working with JPEG 2000

    – Profile is completely commercial viable (baseline profile from the JPEG 2000 compliance document)

        - So you should be able to open with Photshop

- Commercial interoperability

    – Commercial Software and hardware is available today

    – Expect commercial products to be available this year!

Bernie Brower

J2K Profile General Recommendations

- J2K Tiger team defined JPEG 2000 recommended best practices
  - Profile defines parameters for best quality and most functionality for the USIGS architecture

- Recommendations for best image quality results
  - Select the 5-3 numerically lossless for radiometric images (IR,MS, HSI)
  - Defined the usage of the 9-7 visually lossless (Pan, SAR)

- To enable quality scalability
  - 19 truncation quality truncation points to support all applications
  - Lossless (radiometric exploitation), 3.5– 2.0 bpp (MC&G), 2.0 – 1.0 bpp (1st phase visual exploitation), 1.5 – 0.5bpp (Tactical users), and 0.5 – 0.03125 (bandwidth constrained users)

- To enable resolution scalability
  - 5 Levels of wavelet decompositions (R0 – R6 available)

- To enable fast access chipping
  - Tiles of 1024-by-1024 with tile offset in the file header
  - TLM and PLT markers for pointing to chips and quality layers

From the end users point of view

- The JPEG 2000 compression transition will support the end user with:
  - Faster access to images
    - Images can be sent directly from sensor to shooter because we are all using the same standard
    - Images do not have to be reprocessed from one compression standard to another (less processing time)
    - The images are smaller and can be sent quicker
  - Images are better quality
    - Reduced concatenation effects
  - Increase functionality
    - ROI, Progressive transmission, update images, and more

Acronym List

- Image Processing
  - DRA = Dynamic Range Adjustment
  - TTC = Tone Transfer Curve
  - RRDS = Reduced Resolution Data Sets
  - MSE = Mean Square Error
  - NIIRS = National Image Interpretability Rating Scale
  - RMSE = Root MSE
  - Color space transformations
    - Red Green Blue (RGB) Hue Intensity Transform (YCrCb, YIQ, YUV)
  - HVS = Human Visual System

- General
  - COTS = Commercial off the self
  - GSD = Ground Sampled Distance
  - DPI = Dots Per Inch
  - IA = Image Analyst

Bernie Brower

Acronym List

- Compression
  - DPCM = Differential Pulse Code Modulation
  - DCT = Discrete Cosine Transform
  - JPEG = Joint Photographic Experts Group
  - MPEG = Motion Picture Experts Group
  - VQ = Vector Quantization

- Systems/ users/ formats
  - USIGS = United States Image and Geospatial System
  - DDS = Defense Dissemination System
  - NITFS = National Imagery Transmission Format Standards
  - NIMA = Nation Imagery and Mapping Agency
  - TFRD = Tape Format Requirements Document
  - RE/RL = Receive Entity
  - DE = Distribution Entity
  - DoD = Department of Defense

Bernie Brower